Live-Fire Range Sustainment

Energetic Materials as Environmental Contaminants

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Judith C. Pennington, PhD
U.S. Army Engineer Research and Development Center
Environmental Laboratory
Vicksburg, MS

The Challenge

Tools needed to integrate the two are limited.

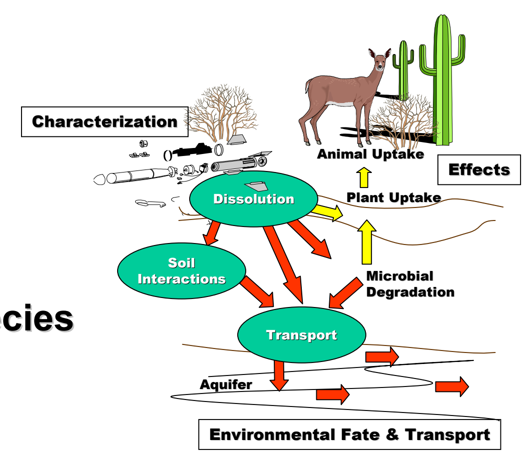
The database upon which to develop those tools is also limited.

Military Readiness

- Training Range Activities (HE)
  - Artillery/Mortar
  - Antitank rocket range
  - Tank firing range (Battleruns)
  - Hand grenades
  - Multi-Use ranges
  - Air to ground bombing/missiles
  - Ground to air missiles
  - Demolition/"blow-in-place"
  - Mines
  - Naval munitions
- Weapon Systems Testing

Environmental Stewardship

- Ground water
- Soil
- Ecosystems
- Threatened and endangered species
- Public health



Origins of Explosives in the Environment

- Manufacturing of explosives
- “Load-and-Pack” operations, filling munitions with explosives
- Live-fire soldier training
- Weapon systems testing
- Demolition of munitions/UXO
- Demilitarization of munitions
- Commercial enterprises

81-mm mortars

275-in rockets

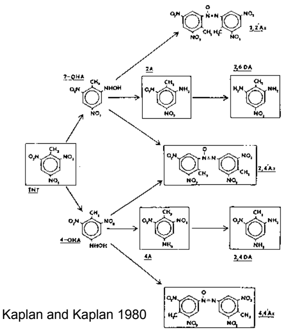
Contaminants of Concern

- TNT
- RDX
- HMX
- DNTs
- Tetryl
- Ammonium picrate
- White phosphorus

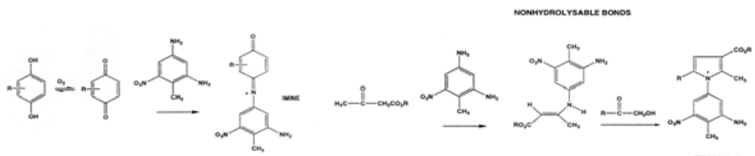
- Others
  - Perchlorate
  - Nitroglycerin
  - PETN
  - Degradation and transformation products
  - Components of smokes, obscurants, pyrotechnics
  - Heavy metals
  - Related organic compounds

TNT Transport/Degradation

- Transformation products are common when TNT is present
- **Attenuation by soils is significant**
- Transport occurs when volume of soluble contamination exceed capacity of soil to attenuate, e.g., manufacturing sites



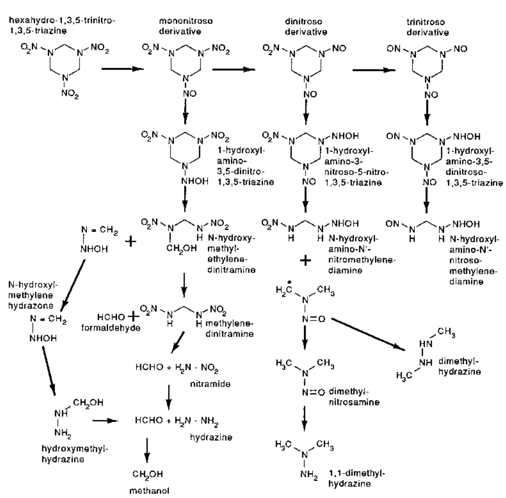
Kaplan and Kaplan 1980



Thorn and Pennington 2001

RDX Transport/Degradation

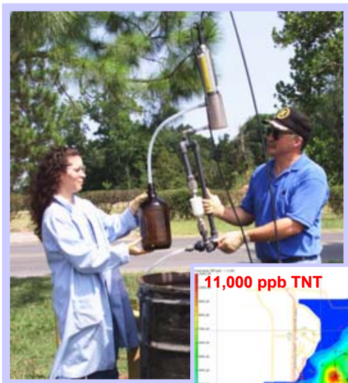
- Mineralization is minimal in the vadose zone, but enhanced under anaerobic conditions
- Some transformation products are undesirable
- **Readily transported from soil to ground water**
- RDX is readily taken up by some vegetation

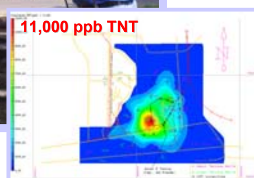


McCormick, Feeherry, and Levinson 1976

Status of Explosives Contamination

Manufacture and load-and-pack sites



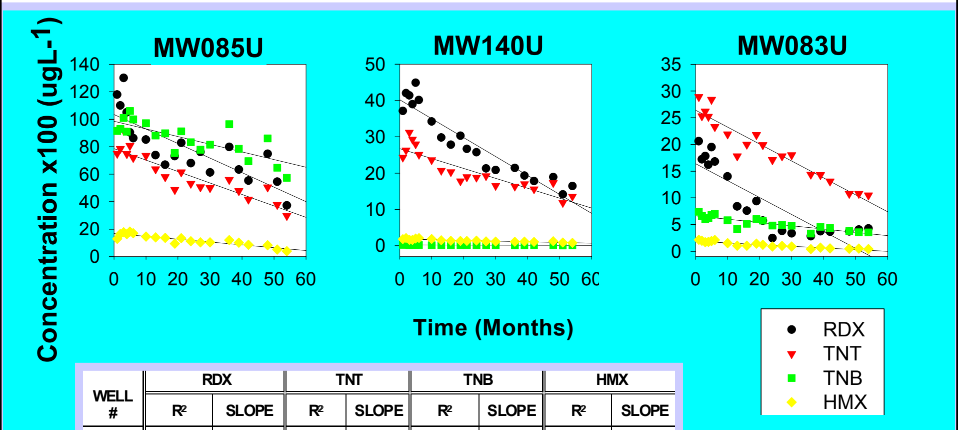


Louisiana Army Ammunition Plant

- Focus of clean-up efforts since early 1980s
- Most heavily contaminated soils and ground water have been treated, or are currently under treatment
  - Incineration • Composting
  - Pump-and-treat • In situ
  - Monitored natural attenuation
- Point sources; originally aqueous

Manufacturing Site

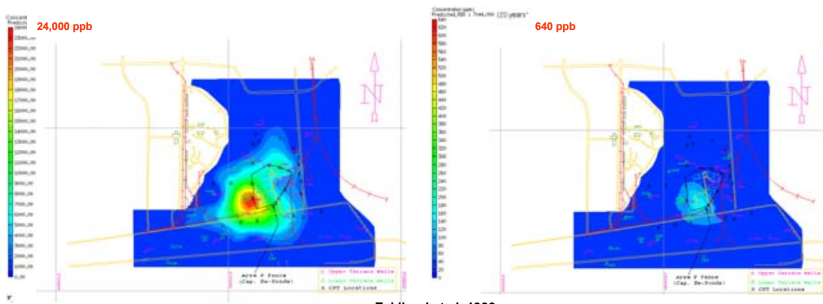
Concentrations in LAAP Ground Water Over Time



WELL #	RDX R^2	RDX SLOPE	TNT R^2	TNT SLOPE	TNB R^2	TNB SLOPE	HMX R^2	HMX SLOPE
0.85U	0.669	-105.864	0.822	-83.337	0.606	-55.781	0.824	-20.597
140U	0.890	-52.185	0.805	-27.363	0.559	-0.236	0.783	-1.952
083U	0.725	-31.665	0.914	-31.710	0.767	-6.201	0.861	-3.166

Pennington et al. 1999

Manufacturing Site: LAAP
Ground Water Model RDX Plume

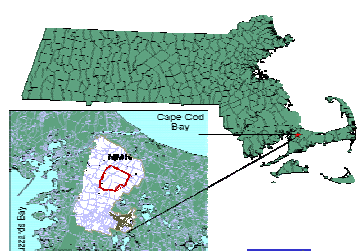


Initial

Zakihani et al. 1999

20 Years

Massachusetts Military Reservation

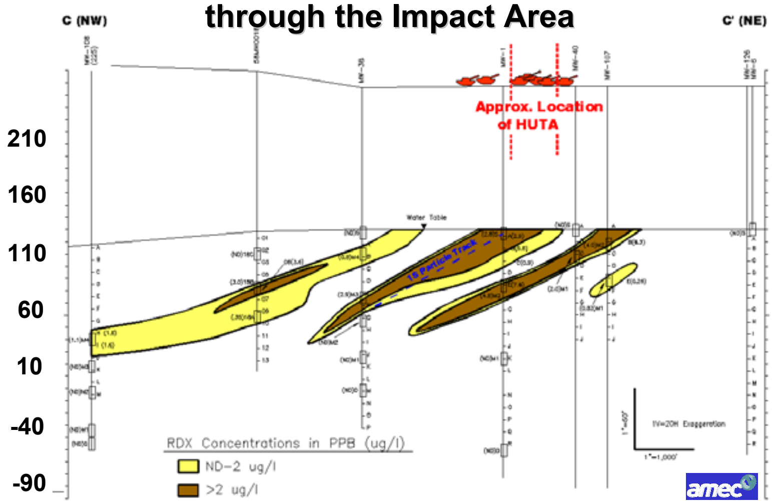


Massachusetts Military Reservation

- 21,000-acre facility located on Cape Cod, MA
- Approximately 14,000 acres of Training Range and Impact Area
- Sits on the Cape Cod Aquifer, a sole source of drinking water for 148,000 permanent and 425,000 seasonal residents
- Soil is highly permeable
- Groundwater exceedance of the Lifetime Health Advisory of 2 ppb for RDX and TNT (one site)
- Soil contaminants include concentrations (ppm) up to
  - 43 RDX, 10 HMX, 17 2,4DNT, 130 nitroglycerin, transformation products of TNT, other organics, and metals
- EPA Order (1997) required
  - Suspension of training
  - Elimination of current and potential sources to aquifer
  - Monitoring plan to assess compliance
  - Restoration of areas disturbed by the action

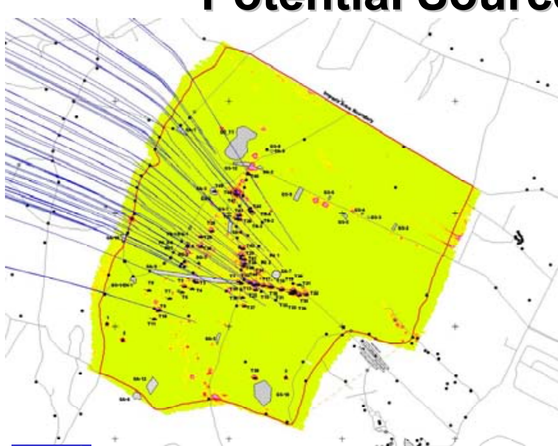
RDX Plumes at MMR

Longitudinal Cross-Section through the Impact Area



MMR Central Impact Area

Potential Sources



- High-order detonations
- Low-order detonations
- Ruptured UXO
- OB/OD sites

Massachusetts Military Reservation

- Investigations for Ground Water Study Program (1997-2002)
  - 2,041 profile samples from 171 soil borings
  - 1,014 wipe samples from UXO
  - 3,495 ground water profile samples from 256 borings
  - 5,233 groundwater samples from 651 monitoring wells at 256 locations
  - 56 documents in 2002 alone
- Ground water contamination
  - Three source locations: Central Impact Area, Demolition Area 1, and J Range
  - Contaminants of Concern: RDX, HMX, 4ADNT, 2ADNT, TNT, 2,4DNT, perchlorate
- Ongoing activities
  - Hydraulic containment at Demolition Area
  - Feasibility Study for Central Impact Area
  - Update of regional ground water model
  - Evaluation of UXO as ground water contamination source
  - Further characterization of J Ranges and other selected sites

Distribution and Fate of Energetics on DoD Test and Training Ranges

SERDP Project CP1155

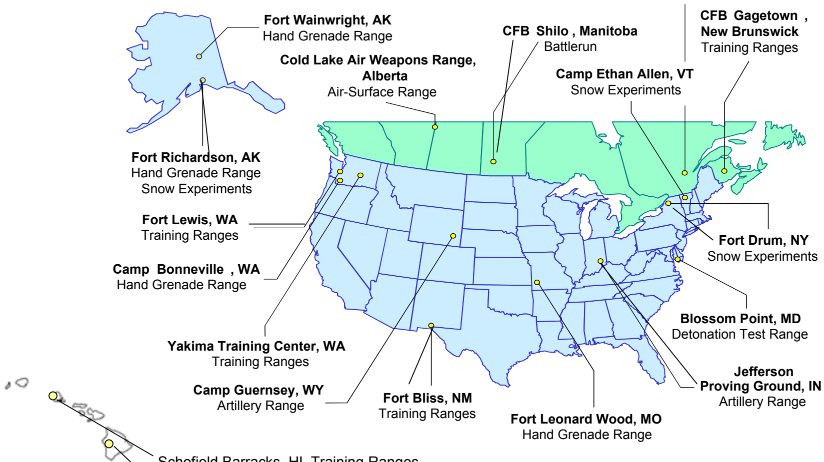


- Range characterization
  - Sampling of residues on active ranges
- Defining residues from controlled detonations
  - High-order detonations on snow
  - Blow-in-place on snow
  - Controlled low-order detonations
- Residues at firing points

Distribution and Fate of Energetics on DoD Test and Training Ranges

SERDP Project CP1155

Ranges Studied Under SERDP



Residue Deposition from Operational Use of Munitions

Munition	Mass in item (RDX, grams)	Residue (RDX, grams)
M67 hand grenade	110	0.000025
105-mm howitzer	1,300	0.000100
81-mm mortar	560	0.001000
60-mm mortar	220	0.000074
40-mm grenade	19	0.001600
120-mm mortar	1,800	0.004100

Jenkins/CRREL 2002

Soil Concentrations Near Low-Order Items (Ft. Bliss)

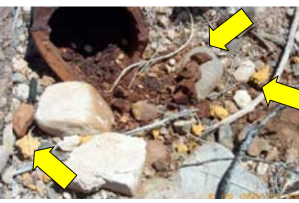
SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research

	Concentration (µg/kg)	
Munition	**RDX**	**TNT**
155-mm	not detected	2,520,000
155-mm	not detected	8,590,000
155-mm	1,780	722,000
37-mm	not detected	1,220
2.75" rocket	1,130,000	13,500
90-mm	678,000	1,110,000

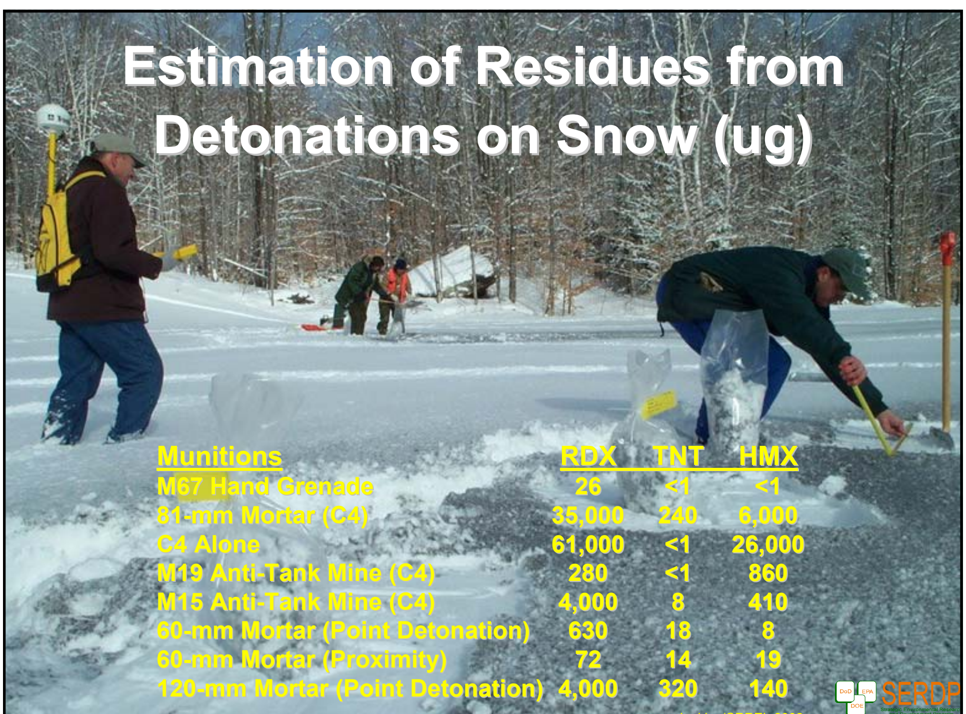
Jenkins/CRREL 2002

Explosive chunks recovered from soil surface

Low-order hand grenade with Comp B chunk inside



Low-order 155-mm projectile with scattered chunks



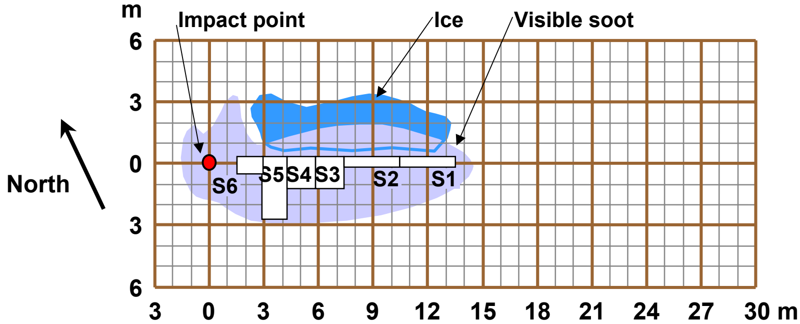
Estimation of Residues from Detonations on Snow (ug)

Munitions	RDX	TNT	HMX
M67 Hand Grenade	26	<1	<1
81-mm Mortar (C4)	35,000	240	6,000
C4 Alone	61,000	<1	26,000
M19 Anti-Tank Mine (C4)	280	<1	860
M15 Anti-Tank Mine (C4)	4,000	8	410
60-mm Mortar (Point Detonation)	630	18	8
60-mm Mortar (Proximity)	72	14	19
120-mm Mortar (Point Detonation)	4,000	320	140

Jenkins/CRREL 2002

SERDP

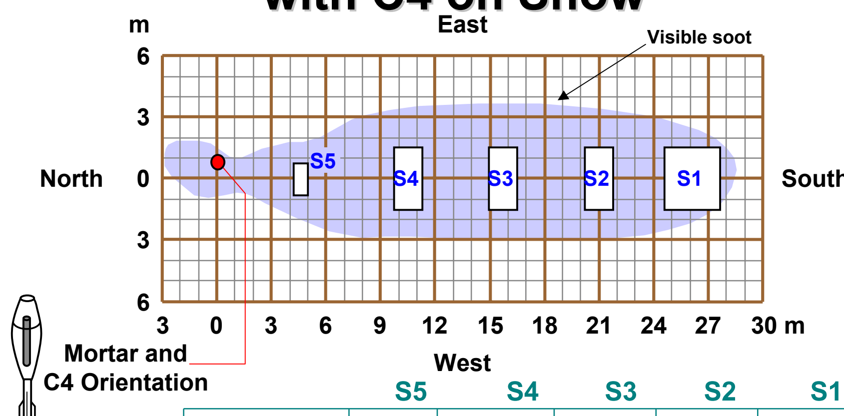
Estimation of Residues from 60-mm Mortar Fired onto Snow



	S6	S5	S4	S3	S2	S1
RDX (µg/m²)	0.60	6.13	0.88	0.33	0.32	0.35
NG (µg/m²)	< d	0.01	< d	< d	< d	< d

Jenkins/CRREL 2002

Estimation of Residues from Detonations of 81-mm mortar with C4 on Snow



	S5	S4	S3	S2	S1
RDX (µg/m²)	12.4	5.2	4.3	1.6	1.0
NG (µg/m²)	802	1,530	367	119	124
TNT (µg/m²)	0.06	< d	< d	0.05	< d

Jenkins/CRREL 2002

Estimating Residues from Controlled Low-Order Detonations

- 60- and 81-mm mortars
- 105- and 155-mm artillery projectiles

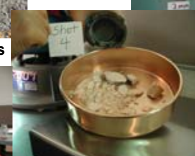
Setting up controlled low-order detonations

Low-order fragments

Residue from controlled low-order detonations

Witness plates and tarp for controlled low-order detonations

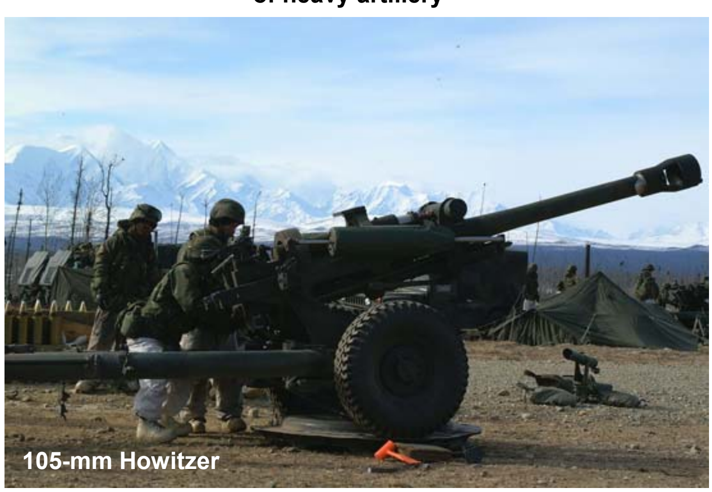
Residue analysis from controlled low-order detonations



TNT chunks from controlled low-order detonations

Residues at Firing Points

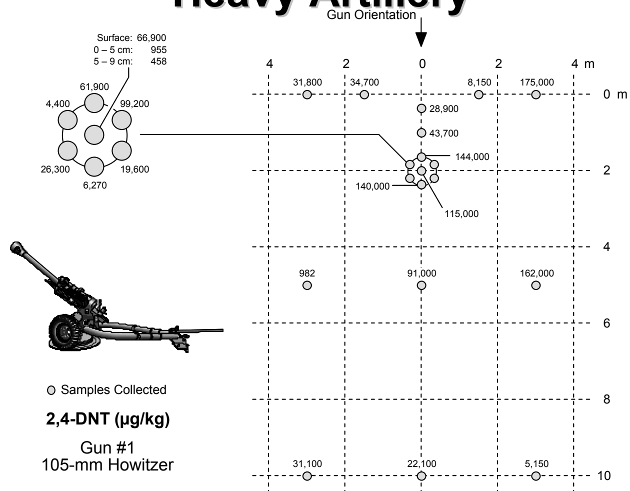
Propellant residues can be significant at firing points of heavy artillery



105-mm Howitzer

Residues at Firing Points

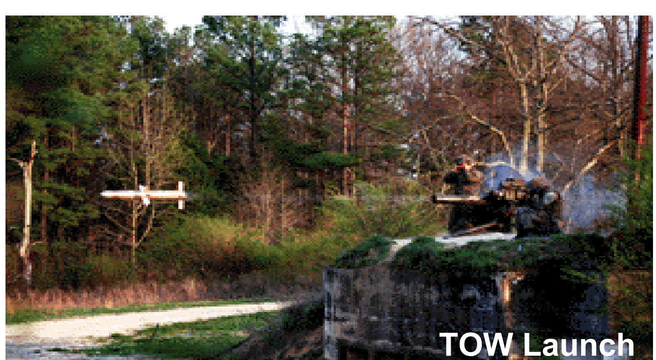
Heavy Artillery



Jenkins-049

Residues at Firing Points

Certain rockets can deposit a continuous trail of residues from firing point to impact and behind the gun



Residues at Firing Points

Perchlorate is a potential contaminant of concern for certain rockets

Titans on the Space Shuttle

- Likely to be common on ranges
- No regulatory limits are set; however, may be imminent
- Regulatory limits may be in the low ppb range (e.g. 1 ppb)
- May also be a problem in BIP (e.g., spotting charge in low-impact training rounds, or LITR)

Status of Explosives Contamination

Live-fire training and weapon systems testing ranges

- Massachusetts Military Reservation (MMR) amec
- SERDP Project CP1155 SERDP
- Characterization
- Fate and Transport
- Environmental Effects
- Challenges
- What we know
- Future directions

Range Characterization/Remediation Challenges of Source and Scale

Expansive size

Extreme spatial heterogeneity

Diverse uses over time

Variable munitions performance low-order

Blow-in-place practices

Various climates

Characterization

What we know

- **Distribution of explosives residues**
  - Random sampling is least effective
  - Integrated sampling approaches are needed
- **Sample handling/analysis**
  - Efficient compositing and subsampling techniques are critical
  - Chemical detection limits must be low for adequate characterization
- **Characteristics of residuals are specific to range firing activities**

Characterization
What we know

Concentrations of residues from high-order detonation are limited

Low-order detonations are significant point sources of contamination

TNT chunks

Firing points as well as impact points can become contaminated

Characterization
What we know

Blow-in-place demolition of UXO can contribute significant contamination

Climate can exert significant effects on the character of residues

Characterization

What we know

- RDX is a significant contaminant of concern on live-fire ranges
- TNT poses less threat to ground water than RDX
- Propellant residues at firing points can be significant

Characterization

Future Directions

Characterize air force and naval ranges




Continue characterization of residues at firing points

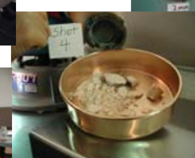
Characterization
Future Directions

Refine estimates of residues from low-order detonations


Setting up controlled low-order detonations


Witness plates and tarp for controlled low-order detonations


Residue analysis from controlled low-order detonations


TNT chunks from controlled low-order detonations

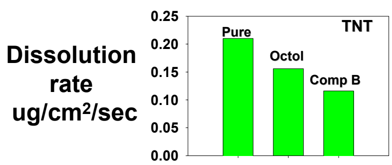

Residue from controlled low-order detonations

Characterization
Future Directions

- Expand range characterization database
- Model the distribution of residues associated with various range uses
- Synthesize data for estimation of source term to use in predictive models and risk assessments
- Develop environmentally safe demolition procedures

Fate and Transport
Challenges

- Corrosion rate
  - Munitions casings
  - Safety
  - Explosives residues



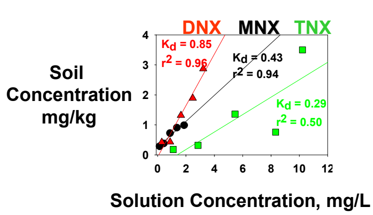
Mean of 3 replicates at 20 °C and 150 rpm stirring rate

- Dissolution rate
  - Compositions

Octol
70% HMX, 30% TNT
Comp B
59.5 % RDX, 39.5% TNT, 1% wax

Fate and Transport
Challenges

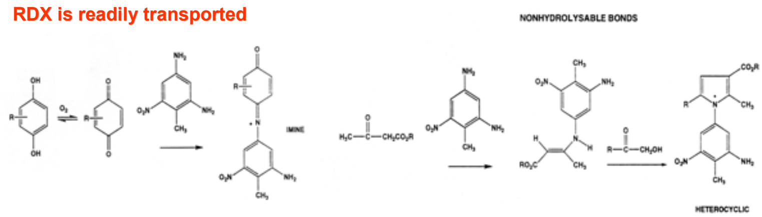
- Transport
  - Various soil/climatic settings
  - Marine environments
  - Degradation products



- Interactions with soils and marine sediments
  - Soil adsorption and desorption
  - Transformation
  - Degradation

Fate and Transport
What we know

- **Soil interactions**
  - **Initial release** from compositions in soils tends to be **locally very high**, approaching temperature dependent saturation
  - Soil ***adsorption*** **will not significantly limit transport**
  - Compositions **dissolve** more **slowly** than individual components
  - **Transformation is slow** and limited except for TNT, which transforms readily to mono amino products
  - **TNT transport is limited by covalent bonding** of transformation products to soils
  - Explosives residues are **resistant to microbial degradation** under conditions typical of ranges
  - **RDX is readily transported**

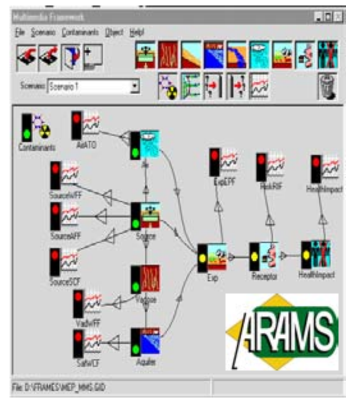


Fate and Transport
What we know

- **Corrosion**
  - Corrosion rates in most environments are slow
  - Casings on many high-load munitions are thick
  - Some UXOs have been in place for extended time periods
- **Climate/Hydrogeology**
  - TNT residues degrades via photolysis
  - RDX is the explosive of greatest concern in ground water

Fate and Transport
Future Challenges

- Process descriptors needed
  - Propellants
  - Smokes and obscurants
- Characterizing corrosion on bottom of UXOs
- Significance of non-HE organics
- Spatial models of the source term
- Transport models
- New generation explosives

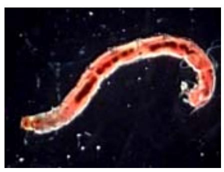


Effects
What we know

- Toxicity varies with species (data are limited)
- Mono amino transformation products of TNT are typically more toxic than TNT
- RDX is readily bioaccumulated by plants
- TNT is rarely translocated from roots

Effects
Future challenges

- **Modeling exposure**
- **Defining representative receptor species for testing**
- **Filling data gaps for munitions compositions, explosives degradation products, and new generation explosives**



Insect larva
Chironomus tentans

Amphipod
Hyalella azteca

Fathead minnow
Pimephales promelas

Challenges Unique to Live-Fire Training Ranges

What to monitor:

- **Number of rounds fired and locations *(How much contamination is/will be out there?)***
- **Number of low-order detonations *(How do you monitor these "hot spots"?)***
- **Contamination in soils resulting from low-order detonations *(Where?)***
- **Contamination in soils resulting from firing point residues *(Where?)***
- **Contamination in ground water resulting from range activities *(Where do you put the wells?)***
- **Contamination of air**
- **Contamination of surface water**
- **Ecological impacts *(What species are sentinel? In which regions of the country?)***

How to monitor:

- **Access to**
  - **Ranges**
  - **Contaminated soils *(finding it)***
  - **Contaminated ground water**
  - **Receptors**
- **Sustaining monitoring systems**
  - **Stability against blasts**
  - **Stability against range fires**
  - **Safety**
- **Scale and heterogeneity**
  - **Representativeness**
- **Release of data**
  - **Sensitivity levels**
  - **Whose data are they?**

Managing the Problem

- Synthesis
  - Environmentally “harmless” residues
  - “Trackable” residues
  - “Self-destructing” residues
- Range Practices
  - Tracking duds and low-order detonations
  - Removing/remediating duds and low-order detonations
  - Tracking firing positions for characterization and remediation
  - Improving blow-in-place procedures
  - Managing range use to minimized residues

The direct approach to cleanup